Wireless Netw (2013) 19:2005–2020
DOI 10.1007/s11276-013-0584-y

A QoE handover architecture for converged heterogeneous wireless networks

**Denis Rosário · Eduardo Cerqueira ·
Augusto Neto · Andre Riker · Roger Immich ·
Marilia Curado**

Abstract The convergence of real-time multimedia applications, the increasing coverage of heterogeneous wireless networks and the ever-growing popularity of mobile devices are leading to an era of mobile human-centric multimedia services. In this scenario, heterogeneous communications will co-exist and ensure that the end-user is always best connected. The rigorous networking demands of wireless multimedia systems, beyond quality-oriented control strategies, are necessary to guarantee the best user experience over time. Therefore, the Quality of Experience (QoE) support, especially for 2D or 3D videos in multi-operator environments, remains a significant challenge and is crucial for the success of multimedia systems. This paper proposes a QoE Handover Architecture for Converged Heterogeneous Wireless Networks, called QoEHand. QoEHand extends the Media Independent Handover (MIH)/IEEE 802.21 with QoE-awareness, seamless mobility and video adaptation by integrating a set of QoE-based decision-making modules into MIH, namely a video quality estimator, a dynamic class of service mapping and content adaptation schemes. The QoEHand video estimator, mapping and adaptation components operate by coordinating information about video characteristics, available wireless resources in IEEE 802.11e and IEEE 802.16e service classes, and QoE-aware human experience. The video quality estimator works without the need for any decoding, which saves time and minimises processing overheads. Simulations were carried out to show the benefits of QoEHand and its impact on user perception by using objective and subjective QoE metrics.

Keywords Multimedia · MIH · QoE · Wireless networks

1 Introduction

The evolution of heterogeneous networking access technologies, real-time multimedia applications and protocols has created a plethora of new wireless connectivity scenarios featuring an ever-increasing number of devices and multimedia networking entities. This heterogeneous multimedia smart environment is changing the lifestyle of users and creating a human-centric multimedia wireless era. Hence the integration of heterogeneous networks in such a scenario, for instance IEEE 802.11, IEEE 802.16 and Long Term Evolution (LTE) in multi-access and multi-operator systems, is bringing about revolutionary changes in the Internet by providing new opportunities, introducing better communication channels and raising the possibility of providing better Quality of Experience (QoE) assurance for users of wireless services.

D. Rosário · E. Cerqueira (✉)
Federal University of Para, Belém, Brazil
e-mail: cerqueira.ufpa@gmail.com; cerqueira@ufpa.br

D. Rosário
e-mail: denis@ufpa.br

A. Neto
Federal University of Rio Grande do Norte, Natal, Brazil
e-mail: augusto@dimap.ufrn.br

A. Riker · R. Immich · M. Curado
University of Coimbra, Coimbra, Portugal
e-mail: riker@dei.uc.pt

R. Immich
e-mail: immich@dei.uc.pt

M. Curado
e-mail: marilia@dei.uc.pt

The multi-access/operator wireless environment will allow mobile users to be "Always Best Connected" (ABC) (including during handover) to the best wireless access network, where seamless mobility will be combined with respect for each individual user′s preferences. Seamless mobility enables mobile users to be always linked to the optimal network so that the user experience can be optimised and maintained even during handovers. In this scenario, the creation of novel cross-layer architectures is required to allow vertical/horizontal seamless QoE-aware handovers in heterogeneous wireless networks [1]. As a means of providing interoperability and seamless mobility in heterogeneous systems, the IEEE introduced the standard called IEEE 802.21 or MIH (Media Independent Handover Services) [2]. The MIH is a middleware for heterogeneous networks, which has a set of protocols and mechanisms that allows IEEE or non-IEEE technologies to be integrated, while ensuring both vertical and horizontal handovers. However, MIH alone is unable to provide either an ABC approach or QoE assurance for videos over wireless clients.

In traditional handover schemes, such as MIH, users are connected to access points that offer the best power present in a received radio signal or Quality of Service (QoS) metrics, such as loss and delay. In heterogeneous networks, the Received Signal Strength Indicator (RSSI) and QoS metrics are not enough, by themselves, to support QoE-aware seamless mobility. This is because these low-level quality metrics cannot measure the subjective aspects of multimedia content with regard to user perception/satisfaction [3]. In view of this, cross-layer heterogeneous wireless QoE architectures with multi-homing, quality estimator, mapping and adaptation are recognised as key factors in the success of future multimedia systems [4, 5].

A mobile multimedia architecture with a video quality estimator must be designed with the aim of estimating user perception at the currently connected as well as candidate access points (which will be used in the handover decision process) with low complexity and processing. This must be able to integrate comprehensive monitoring schemes with service metrics, such as visual codec, Group of Pictures (GoP) length, intra-frame dependency, spatial–temporal (motion and complexity) video activity, network impairments and other relevant factors, such as the capacity of the wireless systems/service classes [6–8]. QoE-aware prediction models can be devised through efficient network cross-layer agnostic content-awareness, QoE monitoring and Artificial Intelligence (AI) techniques along with the corresponding cognitive evaluation of the inputs of the users [4].

One of the key issues when deploying heterogeneous wireless systems is that each domain must support different QoS models (e.g. IEEE 802.11e or IEEE 802.16) and offer the same wireless service classes with different definitions or even service classes with different compositions [9]. One possible solution to this problem would be to define a set of standardisations for the service class definitions so that the service metrics are compatible across different providers. Despite being simple and efficient, this restrains providers from diversifying their business strategies. Another solution is to deploy a dynamic mapping mechanism that automatically maps applications into corresponding classes according to their characteristics and wireless resources in handover periods and thus gives providers the autonomy to form their own service class definitions in accordance with their strategies [9].

The QoE-aware mapping mechanisms must be able to map application requirements and user perception into available wireless service classes on the basis of information about the available service classes within or between wireless networks (multi-access and multi-operators) and scores for the level of video quality given by the quality estimator. During periods of congestion in a selected service class, the adaptation mechanism must maintain the quality level of the 2D/3D multimedia applications, by selecting another service class to map on-going packets or by dropping packets in overloaded queues in accordance with the impact they have on user perception. Thus the minimal quality level of emerging video applications is assured, while optimising the usage of wireless resources and increasing user satisfaction.

This paper proposes a QoE Handover Architecture for Converged Heterogeneous Wireless Networks, called QoEHand. QoEHand extends MIH to allow QoE-based seamless mobility and video quality optimisation through the use of video quality estimator [10], mapping and adaptation schemes. Compared with existing MIH solutions, QoEHand identifies the most suitable connection with the aid of a specifically designed set of decision-making modules, which take into account the QoE needs of the applications/clients, available wireless resources and human experience. In periods of service class congestion, the quality level of video applications is assured by performing a handover to the most suitable candidate networks which have sufficient wireless resources or by actively dropping packets with the least impact on user perception. Simulations were carried out in a multi-operator IEEE 802.11e/IEEE 802.16e system to measure the benefits of the proposed solution and its impact on user perception by employing objective and subjective QoE metrics (more details about QoE metrics can be found in [11]).

This paper is structured as follows. The related works are discussed in Sect. 2. Section 3 details the QoEHand architecture. Simulation results are demonstrated in Sect. 4. Section 5 presents the conclusions and future works.

2 Related works

A proposal for a video quality estimator that relies on the structure (width, length and height) of the video to provide a QoE quality score is introduced by [12]. However, this proposal has not been evaluated in wireless networks and does not take video motion and complexity levels and intra-frame dependency into account in the prediction process as expected for video assessment schemes for emerging wireless networks. Another video quality estimator, known as Pseudo-Subjective Quality Assessment (PSQA) [13], and its extensions [14] use a Random Neural Network to map network impairments and video characteristics of user perception. A set of applications has already used PSQA [15–19]. However, PSQA-based solutions only use QoS parameters, such as packet loss, as input for the assessment scheme and do not consider videos with different temporal and spatial complexity levels during the video quality prediction process.

The main challenges involved in creating an IEEE 802.21 Media Independence Service Layer to optimise the usage of resources in heterogeneous networks are discussed in [2], adopting a modular and self-organised approach. Control modules, such as mobility and video quality estimators, can be integrated into the system. Our proposal uses the same modular and self-organised approach but also adds, analyses and evaluates the benefits of MIH networks integrated with QoE video quality estimator, mapping and adaptation control schemes. An enhanced server for seamless vertical handover in IEEE 802.21 MIH networks is proposed in [20]. Information about the wireless channel conditions is assessed and used to provide seamless mobility. However, this proposal does not take into account the existence of networks with a different class of services, which are expected in future systems. It is also lacking in terms of QoE assessment and optimisation.

Another study of IEEE 802.21 (integrated IEEE 802.11/802.16e) networks is conducted in [21]. The results demonstrate that a wireless device can start its handover operation before the old link has been disconnected, and thus there is a reduction in packet losses and the handover latency. Our proposal follows the same make-before-break approach to provide seamless handover, but we also introduce the QoE video quality estimator, mapping and adaptation support, as required for future heterogeneous networks.

A framework to provide QoS assurance for applications in heterogeneous environments is discussed in [22]. The proposal implements a schedule-based approach that draws on information about delay, loss and network resources and adjusts QoS schedulers to improve the video quality of delivery. However, it does not provide seamless handover or follow its procedures in accordance with the user experience/QoE scheme. A predictive handover scheme to improve service quality in the IEEE 802.21 network is presented in [23]. It explores information about the network conditions, such as RSSI values, from MIH as a determining factor for handover prediction. However, the proposed solution does not perform dynamic mapping and adaptation and does not assess the quality level of applications for enhancing the handover decision process.

Key challenges for optimising QoE in Next Generation Networks (NGN) are detailed in [6]. This study explains the deployment of a QoE management scheme in NGN in general terms. However, our solution will succeed in implementing and validating a QoE handover architecture for converged NGN by extending MIH and its traffic/mobility controllers with QoE video quality prediction, mapping and adaptation schemes. A discussion of how QoE-awareness can improve the distribution of multimedia in networking systems is conducted in [24]. Our proposal extends this work by including a set of adaptation schemes as well as by using an opportunistic seamless mobility scheme to allow wireless clients to be ABC and with QoE support.

Very few works have studied the benefits of an integrated wireless networking architecture with seamless mobility and heterogeneous support as well as QoE-mapping, adaptation and video quality prediction mechanisms from the human standpoint. This is undertaken in the next section, where our proposal seeks to overcome the limitations of current proposals by allowing mobile users to be ABC with QoE support in multi-operator and access wireless environments.

3 A QoE handover architecture for converged heterogeneous wireless networks

The goal of the QoEHand is to ensure QoE-aware seamless mobility and optimisation support for real-time multimedia applications in converged heterogeneous wireless networks. This objective is achieved by extending MIH with key QoE-aware video quality, mapping and content adaptation components. In handover periods, QoEHand enhances MIH in identifying the most suitable connection (and BS) with the aid of a specifically designed set of decision-making modules, which take into account the QoE needs of the current applications, human experience, and available resources in IEEE 802.11e/IEEE 802.16 service classes.

QoEHand agents are implemented, together with both Base Stations (BSs)/Access Points (APs) and wireless nodes, by following the recommendations of the MIH proposal. As presented in Fig. 1, QoEHand extends MIH/IEEE 802.21 through the QoE-aware mapping, video quality estimator and adaptation components. Well-defined

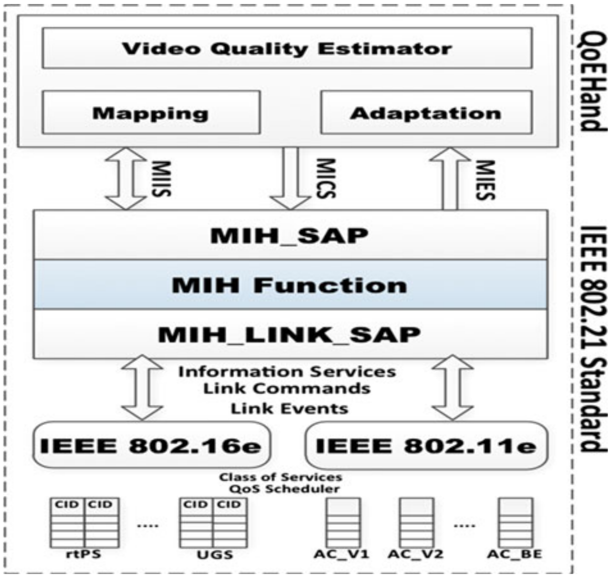

Fig. 1 IEEE 802.21 standard with QoEHand components

interfaces and messages allow a tight communication between IEEE 802.21 and QoEHand elements, such as improving schedulers with a QoE dropping algorithm. Thus wireless devices can always be best connected (with QoE assurance) in multi-operator/access networks.

3.1 QoE video quality estimator

A non-intrusive parametric video quality estimator is implemented by QoEHand agents, as detailed in [10]. The proposal does not need the original video sequence to estimate the video quality, which reduces the computational complexity and at the same time broadens the possibilities of the quality prediction deployment. The video characteristics are collected from the network by using a packet inspector module. In addition, a cluster-based Multiple Artificial Neural Network (MANN) model is implemented to map video characteristics and network impairments into Mean Opinion Score (MOS) as a means of providing results that correspond as closely as possible to a human observer. The QoE video quality estimator operates in two modes, as follows: (1) monitoring the quality level of current video flows. If the predicted MOS indicates a low video quality, the adaptation scheme is triggered to adjust the video content to the current network conditions, as detailed in Sect. 3.3; (2) during the mapping or adaptation process, the video quality estimator is triggered to inform the MOS for videos in each wireless class.

The video quality estimator uses a set of feed-forward back-propagation networks that are supplied with MOS [25]. These parameters enable QoEHand to measure the quality level of videos even when they have different encoding patterns, genres, content types and packet loss rate as expected for typical Internet videos. Additionally, it uses objective parameters from the video encoder and wireless network conditions, as well as information about the perception of humans collected from the MOS experiments. MOS is the most widely used subjective metric, recommended by the ITU [26], and obtained by asking observers to grade the quality of videos on a five-point scale (Excellent, Good, Fair, Poor and Bad).

Figure 2 shows an overview of the video quality estimator components (for more details, see [4, 10]). Each of them is designed to complete one or multiple tasks for the modelling of the quality evaluation model. The content classifier will classify all videos added in the source video database (Component 1) according to their spatial and temporal video characteristics (key information for multimedia quality estimators). The video content characteristics informed by Component 2 together with the percentage of losses of I, P and B frames (collected from network monitoring mechanisms) of a certain GoP (to improve the system accuracy, each ANN is responsible for videos with a specific GoP length, such as 10, 15 or 18) are used by the Quality-Affecting Factor Component to identify the video motion and complexity levels as well as the impact of the transmission on the video frames. At the same time, it is important to keep a distorted video database composed of videos delivered (as expected to be received/viewed by users) in real/simulated networks (such as IEEE 802.21). Thus, Component 3 is responsible for transmitting all videos in wireless networks (with different numbers of users, congestion levels and technologies), getting information on packet loss and delay of video frames, and maintaining a distorted video database with all received flows. Then, a panel of humans evaluates all distorted videos (following the ITU recommendations [26]) to define/score their MOS (Component 4).

Finally, Component 6 is responsible for achieving a final MOS score by using a MANN to correlate video characteristics and network impairments into MOS. QoEHand performs well even with video flows not presented in the video databases. This is possible because MANN identifies patterns of video sequences (which can be different from the training flows) and provides an accurate prediction model in such scenarios. Our proposal has been tested and validated as a dynamic and content-aware quality predictor to estimate the video quality of several types of video content features in realistic multi-operator networks, without any interaction with real viewers and with low complexity/processing. More information about each component is provided below.

- Source video database composer (*Component 1*): responsible for maintaining videos with different

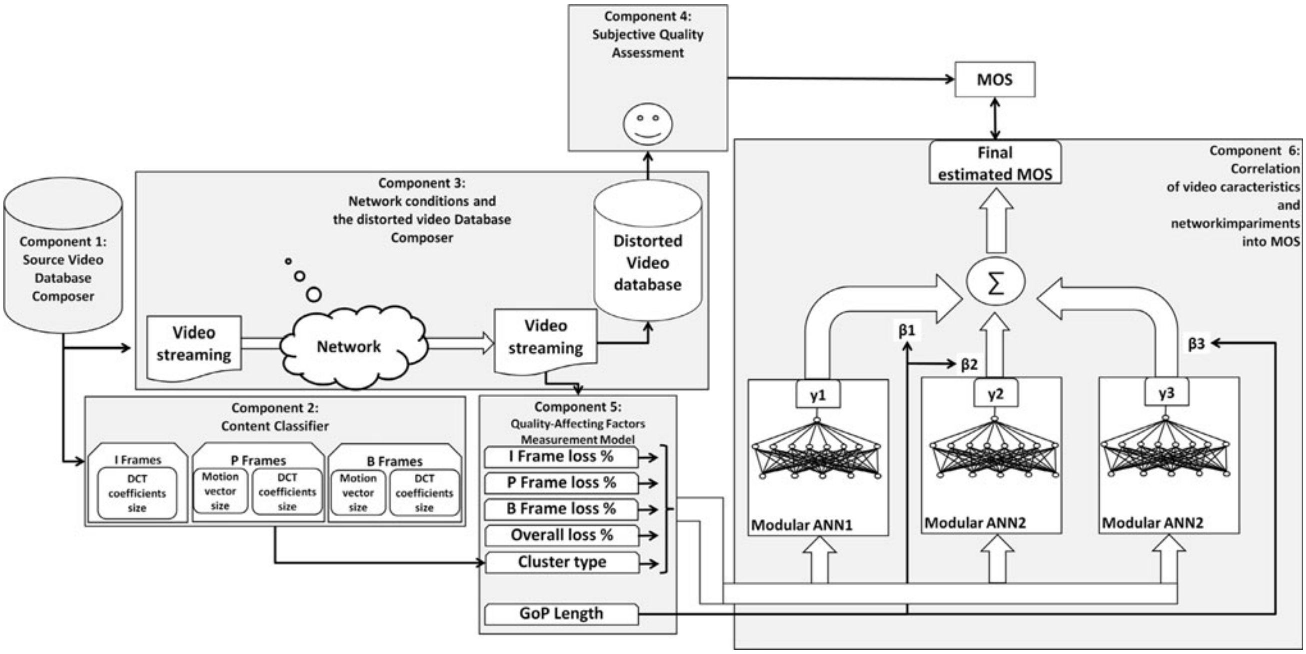

Fig. 2 QoE video quality estimator components and interactions

features as well as their characteristics in a source video database. A video database source should be composed of videos of different types (e.g. news and football matches) with different levels of complexity and motion, as expected for Internet videos. For our experiments, widely used uncompressed sequences of natural scenes that are available in [27] were selected to set up a source database with realistic streaming sequences. The chosen flows contain scenes of different characteristics ranging from very small movements (i.e. a small moving region of interest on a static background) to fast-moving sports clips. This component also performs a hierarchical clustering with Euclidean distance using Ward's method to classify video motion and complexity levels, as recommended in [10], and keeps video motion and complexity information in the database. Video motion and complexity levels can be obtained off-line by using different approaches, such as available MATLAB estimation algorithms (block-based estimation—used in this article), Visual Descriptors of MPEG (describe visual features related to motion) or other available in the literature [28–31].

- Content classifier (*Component 2*): Spatial and temporal activities have been widely recognised as key video metrics that must be used as input for video quality assessment [10]. The user visual perception of video flows is influenced by the number of edges (spatial information—complexity level) in the individual frames and by the type and direction of movement (temporal information—motion level). For our experiments, we use a correlation among Discrete Cosine Transform (DCT) coefficients, Motion Vector (MV) and frame size, and, as resulted, we defined the level of spatial and temporal information as follows: low, medium or high. A deep packet inspection (inspect both packet layer and media encapsulation layer without decoding the video payload) is performed to estimate the DCT/MV size of video frames that are being transmitted [30, 31]. For instance, the video called Mobile [27] has the largest DCT coefficients and thus the highest spatial complexity, while the video Football has the largest Motion Vector and the highest temporal activity. Thus, it is possible to estimate the frame size based on information about DCT/MV size. This information will be further used to predict the impact of a frame lost of a video sequence with a certain motion and complexity level on the user perception.
- Network context conditions and the distorted video database composer (*Component 3*): To investigate and model the relationship between network impairment metrics and human experience, it is necessary to maintain a distorted video database using impairments combined with a packet loss rate and the features of network systems. Section 4 presents the simulation parameters (IEEE 802.11e and IEEE 802.16) used in the tests and to prepare a distorted video database.
- Subjective quality assessment (*Component 4*): Once the video database had been generated, an evaluation plan needs to be carefully implemented to assess all the videos using subjective experiments. The experiments

are carried out by asking a panel of observers to classify the quality level of distorted videos by means of the test method laid down by the relevant ITU recommendations [26]. The sequence is arranged at random for each observer. The opinions of the observers are collected by means of the Absolute Category Rating (ACR) method, which is suitable for large-scale experiments that involve a large number of video applications.

- Quality-affecting factors-measurement model (*Component 5*): Our proposal uses the percentage of losses of the I, P and B frames and video content characteristics as input for the video quality estimator, where the former have to be measured, due to the hierarchical structure of the encoding methods (e.g. MPEG, H.264 or even 3D videos). It should be pointed out that, depending on the levels of spatial and temporal activities carried out in the video content, a GoP is composed of video frames with different sizes, such as 10 or 20 frames.
- Correlation of video characteristics and network impairments into MOS (*Component 6*): MANNs have been used in many research areas to solve problems that include function approximation, classification, and feature extraction, and allow complex tasks to be broken down into smaller and specialised tasks [32, 33]. Each ANN is trained to become a specialist in a specific task of the prediction system (e.g. for videos with a specific GoP length). Hence, it is possible to explore the advantages of MANNs in solving problems that could not be solved with a single ANN. Moreover, the MANNs have a greater capacity for generalisation, high performance, and an ability to provide an accurate prediction model. The findings of our analytical studies were that the GoP length has a strong influence on the prediction of video quality. In view of this, the GoP length was selected as a key parameter and was divided into three specialised ANNs. Each ANN was trained with a specific sub-database comprising GoP lengths of 10, 20 and 30 to obtain better results. The reason for this is that each ANN is responsible for mapping the quality level of videos with a specific GoP length. Thus each ANN has outputs designed for a particular GoP length and, in the case of GoP lengths of 10, 20 or 30, the final MOS is given by the combination of each ANN.

This paper validates the video quality estimator in an IEEE 802.11e and IEEE 802.16e system, as explained in Sect. 4. After the observers had evaluated each video in service classes with different congestion levels, the training process was conducted using the training video database to obtain the mapping between the selected input (video/network) parameters and the MOS. The validation task was carried out with cross-validation techniques to reduce the generalisation error.

If the predicted MOS indicates a low level of quality for the videos, the other QoEHand components will search for a new (more suitable) class to map/adapt the video. The QoEHand considers the available resources in the classes of the current and target networks so that it can offer continuous and seamless services and a satisfactory video content delivery in heterogeneous networks, as expected in future systems.

3.2 QoE mapping mechanism

The mapping process is carried out by drawing on information about the available classes (IEEE 802.11e or IEEE 802.16e QoS models) within or between networks (in multiple paths when possible), application QoS/QoE requirements, the video quality estimator score and mapping policies. The last of these decides which and when mapping methods must be used to carry out a request. After the mapping decision, the MIH QoS scheduler [34] is triggered to map/link the packets in the selected service class.

The mapping policies define two main mapping methods to select the best class for an emerging multimedia application (its flows/components), called *Full* and *Partial-Matching*. A full-matching mapping is achieved when the quality level score of an application in a class is better than the minimal level. If there is more than one class result in the same quality level score, the policy scheme only considers the service class that has more available resources in terms of bandwidth. If the most suitable wireless service class is unable to assure a full matching (due to congestion or the existence of service classes with different configurations in terms of loss, delay and jitter support), the adaptation scheme is triggered to seek a potential adaptation for the applications that match the current network conditions. This adaptation can be carried out by intra-application adjustments or by requesting re-mapping with the aid of partial matching rules.

Depending on the business strategies, the nature of the multimedia content and the video quality level score, a set of dynamic partial matching mapping approaches can be applied as follows:

- Downgrade class mapping: In this approach, a less important class is chosen to accommodate the application that assures a good/acceptable level of quality (video quality estimator score $\geq$ minimal video quality level requirement).
- Scalable coding mapping: This approach takes into account the importance of each scalable flow (scalable video coding) of an emerging multimedia application

during the mapping process. It maps high priority application flows into the best class and lower priority flows into a less significant class.

- Hierarchical component mapping: This approach selects service classes according to the order of priority of different multimedia components. Video communication is much more sensitive to packet loss than audio communication because the human eye can often detect small glitches in a video stream caused by relatively minor packet loss, to the extent that enjoyment and/or understanding are more severely affected. For example, voice has a higher priority than video, therefore the packets of audio flows are mapped to the best class and the packets of video flows to a lower priority class.
- Hierarchical 2D/3D mapping: This scheme maps 2D or 3D video frames based on the importance of each frame type in user experience. In other words, packets carrying *I* frames are allocated to the best class, while packets of *P* and *B* frames are mapped in a less important class.

3.3 QoE adaptation mechanism

As mentioned earlier, one problem arising from multi-operator wireless systems is the fact that each network provider can support different QoS models (e.g. IEEE 802.11e or IEEE 802.16) and can offer the same class of service with different definitions. For this reason, when the mapping process is not optimal (perfect match), the QoE Adaptation adjusts (e.g. downgrades) the quality level of the emerging applications if the network resources in a service class are unavailable (e.g. in congestion periods). The downgrade adaptation process is reversible when resources become available in the previous service class again. In this case, the QoEHand can trigger MIH to handover the wireless client to the old network and maps all the flows into the previous service class. As the success of our seamless proposal depends on adopting a make-before-break approach, the resources that are allocated and not used in previous or candidate service classes are released by soft-state operations, for instance after a handover.

A set of network adaptation profiles can be obtained by the adaptation mechanism to control the quality level of new or current applications. This is achieved as follows:

- 2D/3D frame dropping adaptation: This approach drops packets in accordance with the visual importance of each frame encoded with common hierarchical 2D and 3D MPEG/H.264 codecs. I frames are marked with low dropping priority and B frames with high priority. Due to the intra-frame dependency on hierarchical codecs, when a P-frame is discarded, all of the subsequent P frames and B frames within the same GoP must also be discarded. When an I frame is discarded, all the other frames within the same GoP are dropped.
- Scalable video code adaptation: This approach adjusts the quality level of applications by dropping or adding low important flows of scalable multimedia applications.
- Hierarchical component adaptation: Media flows within an application should be marked with different priorities. Audio packets are marked with low priority and video packets with high dropping priority if voice is more critical for the success/quality of the multimedia application.
- Region of Interest (ROI)/regions in the videos that are of most interest to the viewer: This scheme marks in-ROI (e.g. face) packets with low and out-ROI packets with high dropping priority.

The adaptation module can be configured with different Adjustment Level values. These values indicate which applications must be adjusted or the number/percentage of new or current applications to be adapted. Additionally, other adjustment level parameters, such as the population size of each application group, social relationships, cost/price, user location, static/mobile applications and high-rate applications, can be included in the decision-making process. For instance, elastic traffic must be dropped first, or else the system can be configured to drop less important frames of the video during periods of congestion.

A simple example of an adaptation procedure is when a wireless service class is congested (queue is full) and the IEEE 802.11e/16e schedule algorithm is triggered to adapt the application to the current network conditions by dropping less important frames in a real-time video sequence. As shown in Fig. 3, if the P2 frame is lost, then B3, B4, B5, and B6 cannot be totally reconstructed by the receiver and will waste scarce wireless resources. Therefore, if the P3 frame is marked to be dropped and the P2 frame has been dropped before, it is preferable to verify if there is a packet in the queue that contains a B3, B4, B5, or B6 frame to be discarded and queue the incoming packet with the P3 frame.

Taking the frame dependence into account, when a packet is marked to be dropped, the adaptation mechanism checks if it has broken dependencies. If so, it is dropped. If not, the queue is searched for a packet with broken dependencies. If it is found, the packet is dropped from the queue and the incoming packet is added to the queue. Otherwise, the incoming packet is rejected, as described in Fig. 4. The computational complexity of Algorithm 1 (Fig. 4) is O(n). As soon as there is an incoming packet and the queue is full, the mechanism has to search frames with broken dependencies in the queue. Hence in the worst case,

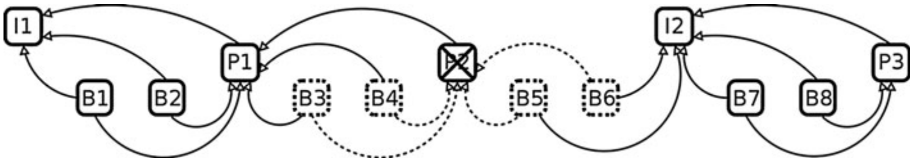

Fig. 3 MPEG structure with broken dependences

Fig. 4 Algorithm for frame dropping adaptation

Algorithm 1. Adaptation mechanism to drop frames

```
if queue.is_not_full() then
    queue.enqueue(packet)
else
    if hasBrokenDependences(packet) then
        drop(packet)
    else
        packetToRemove = queue.getFrameWithBrokenDependences()
        if packetToRemove then
            queue.dequeue(packetToRemove)
            queue.enqueue(packet)
        else:
            drop(packet)
        end if
    end if
end if
```

the adaptation scheme has to search the whole queue, which has a size of *n*.

3.4 QoEHand: MIH integrated architecture

After introducing the functionalities of the mapping, adaptation, and video quality estimator, QoEHand will be described and integrated in an IEEE 802.21 system. A simple algorithm of a session connection setup is presented in Fig. 5. The computational complexity of Algorithm 2 is O(*n*), where it has the method quality_estimator (it calls the video quality estimator to predict the quality of video flows in the selected/most suitable classes), which needs parameters from both *n* videos and *m* service classes to assess the quality level of videos. Since *m* represents a small number of parameters (e.g. available bandwidth, loss, delay and jitter), it is possible to conclude that the algorithm has a computational complexity cost of O(*n*).

Each BS or AP (both with MIH) informs before the connection (both IEEE 802.11e and IEEE 802.16), which service classes (including the current channel conditions in terms of loss, delay, and bandwidth) are available to connect the application of the wireless devices. This information is used as input for the video quality estimator to define a MOS value for the video in each class. Based on information about MOS and current classes, the mapping mechanism will choose the best class to be allocated for the multimedia application. Upon selecting a class (e.g. Access Category 1 in IEEE 802.11e or Unsolicited Grant Service (UGS) in IEEE 802.16e), the BS/AP establishes a connection, where it links the user to a class with QoE assurance. After that, the user starts to receive the required content. For cost reasons (it can be easily configured by the administrator), QoEHand will try to map the video flows in IEEE 802.11e networks before handover to IEEE 802.16e systems in case of failure (not a perfect match).

Fig. 5 Algorithm for a connection setup session

Algorithm 2. Connection setup

```
MIH.connectionInitTrigger()
By using MIH_LINK_SAP
MIH.capabilitiesDiscovery.req()
if QoEHand.mapping (qualityEstimator(videoParameter.list(), serviceClass.list())) == perfect then
    MIH.connectionInitRequest(new)
Else
    QoEHand.adaptation.request(qualityEstimator(videoParameter.list(), serviceClass.list())
end if
```

Details about MIH and QoEHand are discussed as follows. The MIH establishes communication between the lower and upper layers on the basis of a set of IEEE 802.21 primitives defined as Service Access Points (SAPs). There are three SAPs: *MIH_SAP*, *MIH_NET_SAP* and *MIH_LINK_SAP*. The *MIH_SAP* allows the communication between the MIH and the upper layers. The *MIH_NET_SAP* is used to exchange information between MIH entities. The MIH_LINK_SAP is the interface between the lower layers and MIH [34, 35].

The *MIH_LINK_SAP* is responsible for giving information about the service class parameters of the MAC layer technologies to the upper layers. QoEHand will use this information for quality estimation, mapping and adaptation procedures. The mapping can increase user perception and guarantee the quality level support in both the IEEE 802.11e and IEEE 802.16e systems. Based on the QoEHand output (e.g. video quality score), the MIH module in the mobile client is triggered to choose one (or a new) network to be connected, where all video flows are mapped or adapted to the best service class.

When a wireless node detects a Target/Candidate/Foreigner Network, the MIH module sends an *MIH_LINK_DETECTED* message to inform the Target Network that there is a new client in a coverage area, as shown in Fig. 6 (discovery phase). The Target Network sends an *MIH_LINK_PARAMETERS_REPORT* to a wireless device, where the available classes and their conditions are informed. After that, the QoEHand (QoEHand phase) in the Current Network measures and compares the level of video quality in the current and foreign service classes (by using the video quality estimator) and triggers the mapping mechanism to select the best service class for the multimedia applications. If the quality level score in the target network is higher, QoEHand informs the mobile node (by using internal interfaces) about a handover decision. The seamless handover is initiated by using an *MIH_HANDOVER_INITIATE*. The handover can also be triggered in congestion periods when the video quality estimator detects a class in a target network that can ensure a better level of quality for ongoing video flows. If a full match is not possible, the adaptation scheme is requested to adjust the application quality level to the current channel conditions.

4 Performance evaluation and results

QoEHand was evaluated using the Network Simulator 2 (NS2) and Evalvid (to control the video distribution). The objective was to analyse the benefits of QoEHand and its impact on IEEE 802.11e and IEEE 802.16e networks compared with a system without QoEHand (without video prediction, mapping and adaptation—and only with MIH functionalities), by measuring objective and subjective QoE metrics. The QoEHand video quality estimator MANN was formed with the aid of MATLAB. The Real Time Protocol (RTP) payload header includes a field that indicates the current frame type (i.e. I, P, or B frames).

Four profiles were configured in the system to determine the benefits of QoEHand with different scenarios and experiments: (1) Pure_MIH (without QoEHand); (2) QoEHand_Full, when a full mapping match is achieved during the handover and there are available resources in the service class of the foreign network; (3) QoEHand_Part profile, in which a partial matching approach (downgrade class mapping) is used to re-map all the packets of a video sequence into a less important class in the target network, because the most suitable wireless service class cannot assure full-matching (e.g. due to congestion); (4) QoEHand_Drop (frame dropping adaptation), which adapts the video quality level by dropping video packets in descending order of importance, from the standpoint of the user.

The main objective QoE metrics, Structural Similarity Metric (SSIM) and Video Quality Metric (VQM), are obtained by using the MSU Video Quality Measurement

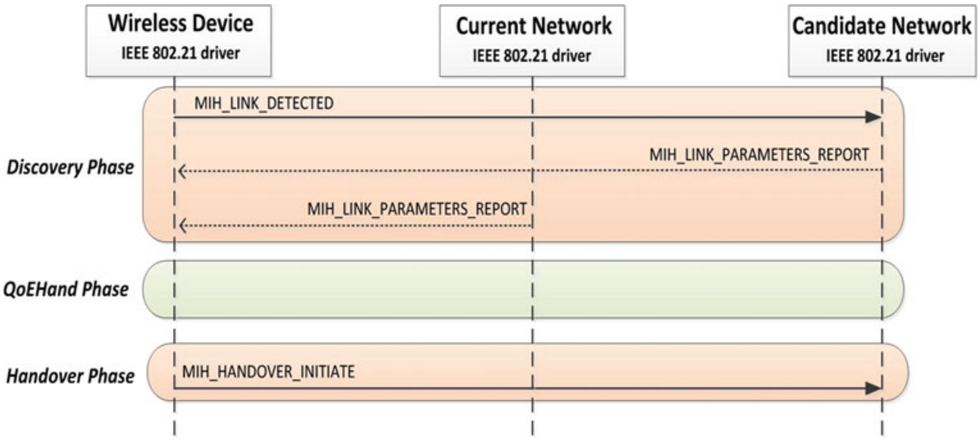

Fig. 6 Signalling messages and operations for a handover process

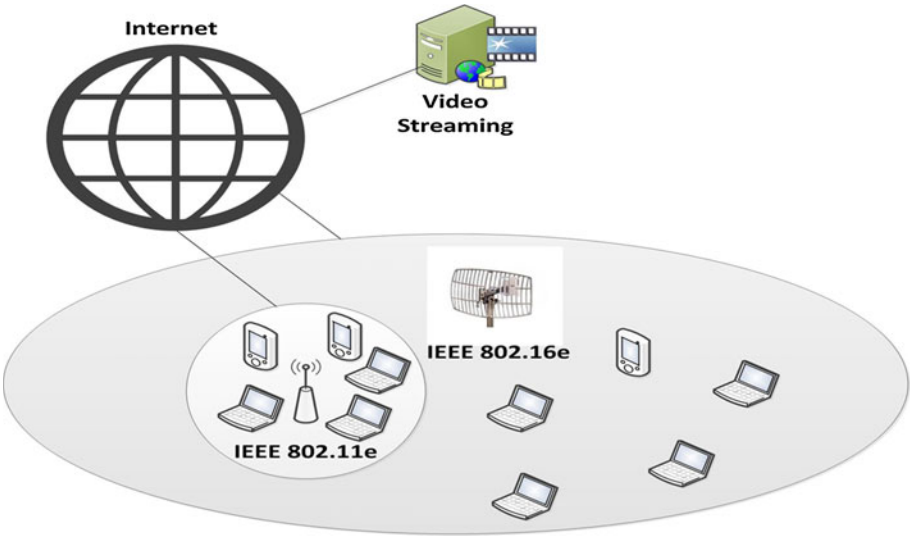

Fig. 7 Multi-access simulation topology

Tool (VQMT). The SSIM index is a value between 0 and 1, where 0 stands for zero correlation with the original image and 1 stands for exactly the same image. The VQM uses the original and the processed video as input and verifies their quality level on the basis of human eye perception and subjective factors, including blurring, global noise and colour distortion. The VQM values vary from 0 to 5, where 0 is the best possible score.

The ITU-T MOS recommendation was used for a subjective evaluation with 55 observers. They had normal vision and their ages ranged from 18 to 45. The observers included undergraduate students, postgraduate students, and University staff. The Single-Stimulus (SS) method was used in the experiments because it is suitable for large-scale tests where a processed video sequence is displayed by itself, without being paired with its unprocessed reference version. The test platform used was a Desktop PC with Intel Core i5, 4GB RAM and a 21” LCD monitor. The videos were played in the centre of the monitor against a neutral grey background. A software tool was implemented to display the videos and collect user scores.

Ten different well-known Internet video sequences were selected for the experiments (Akiyo, Container, Coastguard, Highway, Football, Hall, Mobile, Grandma, News, Silent) with different levels of complexity and motion [27]. The video sequences were encoded in MPEG4 format and the duration varied from 10 to 30 s. The GoP length was 18, which is what can be expected for common Internet video streaming. To provide a large enough video database and increase the reliability of the system, each selected video was simulated 10 times by varying the congestion periods (from 0 to 50 %—in 5 % increments) in a service class, resulting in a total of 100 (received) videos with different packet loss rates (distorted video database).

Table 1 Simulated parameters

	IEEE 802.11e	IEEE 802.16e
Rate transmission	11 Mbps	75 Mbps
Service classes	AC_V0 and AC_V1	rtPS and nrPS
Coverage area	50 m	500 m
Scheduler	–	Round Robin (RR)
Video	Resolution: 176 × 144 CIF	
	Frame rate: 30 frames/s	
	Colour mode: Y, U, V	
Queue	Drop tail (40 ms delay)	
Packet size	1052 bytes	
Maximum fragmentation packet	1024 bytes	
Default propagation model	Two-ray ground	
Packet loss	0–50 % (in 5 % increments)	
Number of simulations	100	
Confidence interval	95 %	
Number of videos	10	

QoEHand performs well in both fixed and mobile scenarios, where the handovers can be triggered due to user mobility or due to congestion in a class. In our experiments, we assume that the wireless nodes are fixed, IEEE 802.11e and IEEE 802.16e interfaces are implemented, and the handover for a new network or class happens due to congestion. The goal of our experiments is to measure the quality level of video applications over an IEEE 802.21 system. Figure 7 shows the multi-access scenario proposed to evaluate QoEHand, which is used in typical MIH tests (more details in [36]). Table 1 presents the simulation parameters.

The MIH multi-access simulation environment with all four profiles (Pure_MIH, QoEHand_Full, QoEHand_Part profile, and QoEHand_Drop) is composed of a source node, which implements 10 real-time video generators, and 10 wireless devices (five in each network—IEEE 802.11e or IEEE 802.16e). Two service classes are configured in each wireless system [IEEE 802.11e—AC_V0 and AC_V1; IEEE 802.16e—Real-time Polling Service (rtPS) and Non-real-time Polling Service (nrPS)]. Before the congestion periods, all receivers in the IEEE 802.11e and IEEE 802.16e networks are connected to AC_V0 and rtPS classes, respectively. The service class, in which the user is receiving the video in the current network, will experience network congestion varying from 5 to 50 % (in 5 % increments) of the underlying capacity by concurrent traffic. Hence, QoEHand will interact with MIH to adjust (handover, re-mapping or drop packets) the video quality level based on one of its three profiles (QoEHand_Full, QoEHand_Part and QoEHand_Drop). To achieve a confidence interval of 95 %, each test was repeated 10 times for each scenario, resulting in a total of 100 experiments.

The numerical results reveal that during the handovers QoEHand introduces an average latency of 2 % to configure its mapping and adaptation mechanisms along new paths. For example, it represents 3 ms when the delay consumed during the mobility process is 150 ms. As QoEHand adopts a make-before-break approach, the handover latency is seamless for the users. As illustrated in Fig. 8, the MOS results show that QoEHand ensures an excellent quality level for the videos during congestion periods when the QoEHand_Full and QoEHand_Part profiles are used. In the QoEHand_Part, the videos still have a good-to-excellent quality level even when re-mapped to a less important class (nrPS or AC_V1) with a packet-loss rate of approximately 2 %. On the other hand, the QoEHand_Drop attempts to keep the application at an excellent quality level up to 10 % of congestion and at a good/regular quality level of up to 30 % of congestion. Moreover, when the Pure_MIH is used, the video quality level is considered poor by all observers if there is a minimum of 10 % congestion in a wireless class. When an I frame is dropped, the error is spread through the rest of the GoP and the quality is bad/poor, because the MPEG decoder uses the I frame as a reference point for all other frames within a GoP.

Figure 9 shows the SSIM values obtained from all the experiments. When the QoEHand_Full is used, the SSIM value is, on average, approximately 7, 21 and 40 % better compared with the profiles of QoEHand_Part, QoEHand_Drop and Pure_MIH, respectively.

Table 2 summarises the SSIM values for the video Highway when the system is configured with both QoEHand_Full and Pure_MIH profiles and a congestion of 5 % is experienced.

The VQM results for all the tests are shown in Fig. 10 and demonstrate the benefits of QoEHand profiles in a QoE-aware converged wireless network (e.g. by analysing blurring, global noise, block distortion and the colour distortion of the videos). The QoEHand_Full profile kept the VQM values at around 0.75 throughout the experiments. Compared with the QoEHand_Full profile, the QoEHand_Part reduced the video quality level by 0.3, on average, for all the simulations. In congestion periods of a service class, the QoEHand_Drop keeps the VQM values at <1 when the congestion rises to 10 %. As the B and P

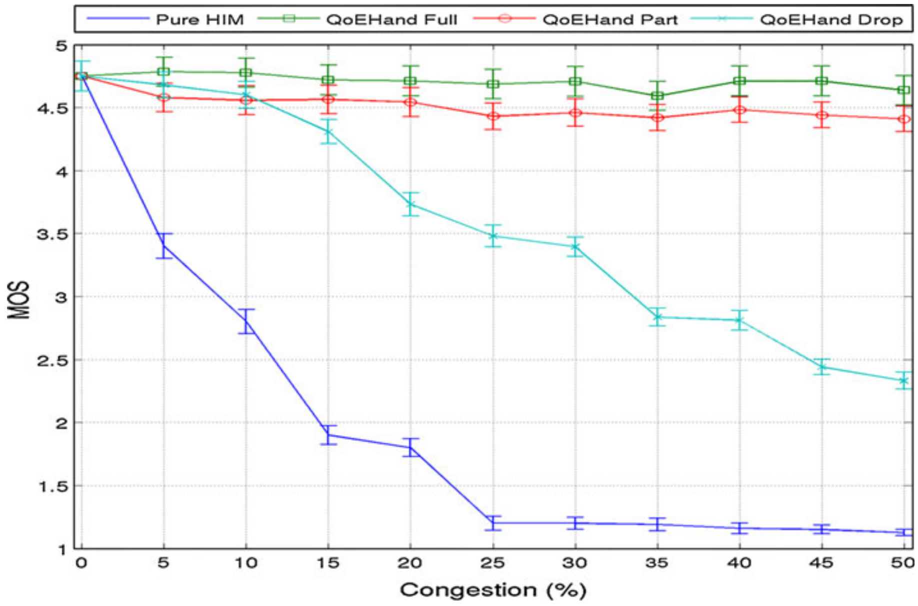

Fig. 8 Congestion × MOS for all the profiles

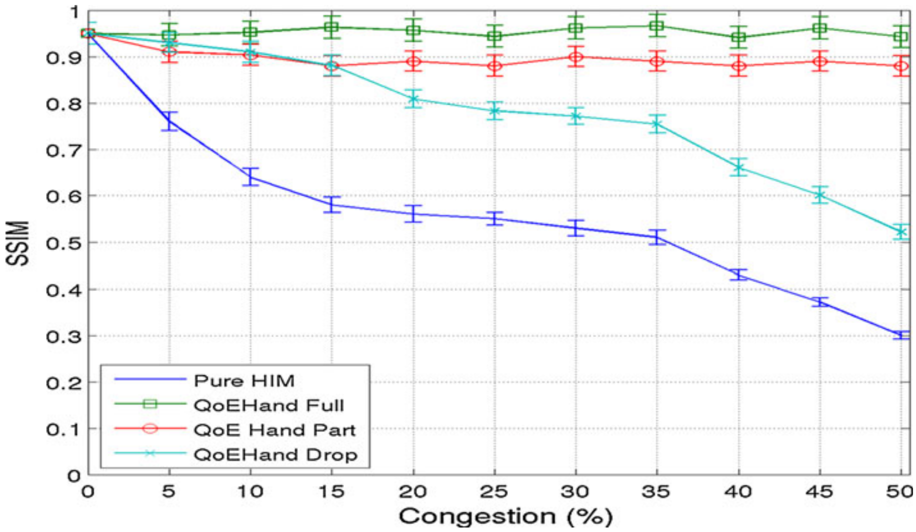

Fig. 9 Congestion × SSIM for all the profiles

Table 2 SSIM values for the Highway video

	Pure_MIH	QoEHand_Full
Average SSIM	0.76	0.96
Maximum SSIM	0.78	0.97
Minimum SSIM	0.74	0.95
Standard deviation SSIM	0.04	0.03

Table 3 VQM results for the Grandma video

	Pure_MIH	QoEHand_Full
Average VQM	1.8	0.55
Maximum VQM	1.9	0.6
Minimum VQM	1.7	0.52
Standard deviation VQM	0.02	0.03

frames are discarded first, the impact on user perception is kept to a minimum when the system is configured with QoEHand_Drop. If it exceeds a congestion rate of 5 %, the Pure_MIH profile can no longer ensure the minimal quality level for the videos.

Table 3 summarises the VQM results for the video Grandma when the system is configured with both QoEHand_Full and Pure_MIH profiles and suffering a congestion of 5 %. While QoEHand_Full aims to keep the VQM at 0.55, a system with only MIH has a VQM that is three times worse.

To show the impact of QoEHand_Full and QoEHand_Drop (compared to the pure MIH control mechanism) from the standpoint of the user when the system is

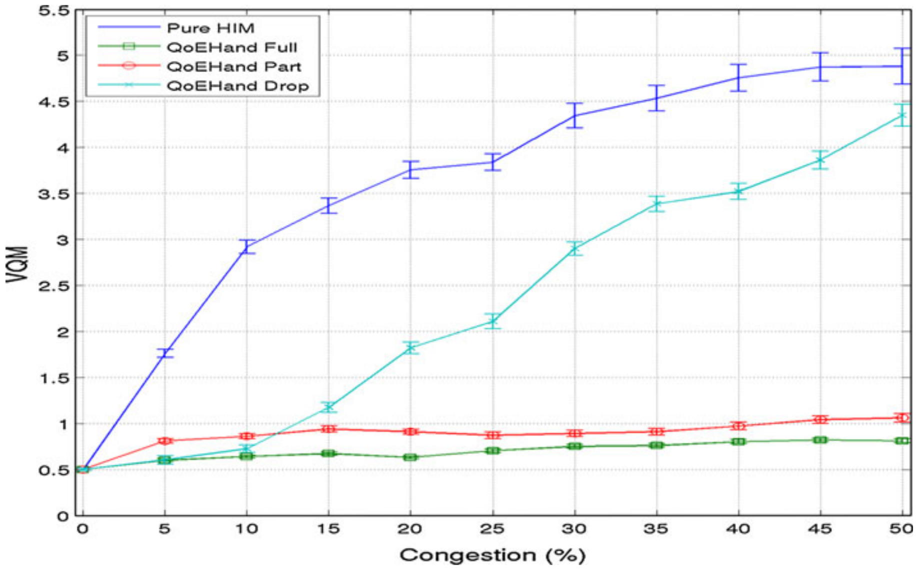

Fig. 10 Congestion × VQM for all the profiles

Fig. 11 Frames of Highway and Grandma videos with different profiles

suffering 5 and 10 % of congestion, random frames were selected from the transmitted videos, as displayed in Fig. 11. However, among the ten video sequences used in our evaluation, only frames from Highway and Grandma video sequences were selected. The remaining files were not depicted to facilitate the analysis, because they reveal marginal variations in the results (we can find similar observations).

The benefits of the QoEHand mechanisms in the delivery of multimedia content with a minimal video quality level support are visible in all frames of Fig. 11. For example, by using Pure_MIH the frame has a higher distortion of the woman's face for the Grandma video sequence, and for many real-time multimedia applications, e.g. video conference, this is not acceptable. Additionally, the displayed frames from the Highway video sequence transmitted through Pure_MIH were lost, and thus they were reconstructed based on the previously received frames. In contrast, QoEHand_Drop and QoEHand_Full delivered the frames with few distortions. This is due to the reasons explained above for SSIM and VQM results.

After exploring the impact of all QoEHand components in multimedia wireless systems, we highlight the accuracy of the video quality estimator in assessing the quality level of real-time video sequences not (previously) included in the video database. New experiments were carried out in the same simulation scenarios (congestion levels and number of repetitions—95 % confidence interval), where two new MPEG4 videos were used in the simulations, named Flower and Mother (10 s and GoP size of 18) [27]. Flower has high spatial and medium temporal complexity levels (similar to Mobile—contiguous camera and motion scenes with many small details), while Mother has low spatial and temporal activities (similar to Akiyo—small moving region of interest on a static background).

The efficiency of QoEHand is compared with widely used QoE metrics, such as the PSNR, VQM, and SSIM, as well as PSQA and MOS collected from real observers. Our results rely on a key estimation method, namely Pearson Correlation Coefficient (PCC), as recommended by the Video Quality Experts Group (VQEG), where 1 indicates a perfect match between the predicted measurements and the subjective ratings and 0 indicates no correlation.

On average, the PCC result obtained by QoEHand is 0.9. When the system is configured to analyse the quality level of videos based only on PSNR, SSIM, VQM, and PSQA, the PCC values are 0.12, 0.34, 0.39 and 0.81, respectively. The results confirm that objective metrics perform poorly compared with those of MOS, PSQA and QoEHand. By comparison, the PCC for the videos Mobile and Akiyo (included in the source video database) is 0.92. QoEHand performs well even with video flows not presented in the video source and destination databases. This is possible because, in addition to the benefits of MANN in identifying patterns of video sequences, which they were trained to deal with (as happened with Flower and Mother), and providing an accurate prediction model, our video quality estimator uses a set of feed-forward back-propagation networks that are supplied with subjective MOS scores. Thus these parameters enable QoEHand to measure the quality level of videos even when they have different encoding patterns, genres, content types and packet loss rates.

5 Conclusion and future work

Future heterogeneous multimedia multi-access/operator wireless systems will provide Internet connectivity to thousands of devices in a ubiquitous way, where users will be able to access, share and send video flows anytime and anywhere. Therefore, new solutions are needed to ensure that end-users will always be connected to networks that are able to provide the best QoE for their applications. This paper introduced QoEHand to enhance human perception and optimise the usage of wireless resources in competitive converged wireless systems with low complexity and processing. QoEHand extends MIH with QoE assurance by coordinating quality estimator, mapping and adaptation schemes. Due to its modular approach, QoEHand can be adjusted to operate with different technologies, such as LTE, and wireless service classes.

Simulations were carried out to demonstrate the impact and benefits of QoEHand in an IEEE 802.11e and IEEE 802.16e multi-operator system. The results obtained show that QoEHand provides a better quality level for real-time video applications compared with a pure MIH scheme. The results reveal that QoEHand_Full and QoEHand_Part profiles allowed the video to keep an excellent MOS during all the experiments, while QoEHand_Drop maintained videos at an excellent quality level up to 10 % of congestion.

In future studies, QoEHand will be analysed in a mobile dynamic heterogeneous scenario with dozens of mobile users and videos competing for resources in a converged IEEE 802.11e, 802.16e and LTE system. Moreover, a testbed will be configured to show the impact of QoEHand on real systems by using OpenFlow. Finally, new motion and complexity estimation algorithms will be analysed, implemented and evaluated with QoEHand.

Acknowledgments This work was funded by The National Council for Scientific and Technological Development (CNPq). Authors would like to thank PROPESP/FADESP/UFPA. Eduardo Cerqueira receives a CNPq Fellowship.

References

1. Roy, J. J. J., Vaidehi, V., & Sricharan, M. S. (2011). QoS guaranteed integration methodology for a WLAN–WiMAX heterogeneous network. *Computers & Electrical Engineering, 37*(3), 261–274.
2. De La Oliva, A., Banchs, A., Soto, I., Melia, T., & Vidal, A. (2008). An overview of IEEE 802.21: media-independent handover services. *IEEE Wireless Communications, 15*(4), 96–103.
3. Venkataraman, M., & Chatterjee, M. (2011). Inferring video QoE in real time. *IEEE Network, 25*(1), 4–13.
4. Aguiar, E., Riker, A., Mu, M., Zeadally, S., Cerqueira, E., & Abelem, A. (2012). Real-time QoE prediction for multimedia applications in wireless mesh networks. 4th IEEE Future Multimedia Network Workshop/9th IEEE Consumer Communications and Networking Conference, CCNC 2012, Las Vegas, USA.
5. Al-Surmi, I., Othman, M., & Mohd Ali, B. (2012). Mobility management for IP-based next generation mobile networks: review, challenge and perspective. *Journal of Network and Computer Applications, 35*(1), 295–315.
6. Zhang, J., & Ansari, N. (2011). On assuring end-to-end QoE in next generation networks: challenges and a possible solution. *IEEE Communications Magazine, 49*(7), 185–191.
7. Sousa, R., Mota, E. S., Silva, E. N., Paixão, K. S., Faria, B. H. C., & Neto, J. B. P. (2010). GoP size influence in high resolution video streaming over wireless mesh network. *IEEE Symposium on Computers and Communications, 2010*, 1–3.
8. Huszák, Á., & Imre, S. (2010). Analysing GoP structure and packet loss effects on error propagation in mpeg-4 video streams. 4th International Symposium on Communications, Control and Signal Processing (ISCCSP), 1–5.
9. Matos, F., Matos, A., Simoes, P., & Monteiro, E. (2011). QoS adaptation in inter-domain services. 12th IFIP/IEEE International Symposium on Integrated Network Management, 257–264.
10. Aguiar, E. S., Riker, A., Abelem, A., Cerqueira, E, & Mu, M. (2012). Video quality estimator for wireless mesh networks. IEEE/ACM 20th International Workshop on Quality of Service (IEEE/ACM IWQoS 2012), 1–9.
11. Mu, M., Romaniak, P., Mauthe, A., Leszczuk, M., Janowski, L., & Cerqueira, E. (2012). Framework for the integrated video quality assessment. *Multimedia Tools and Applications, 61*(3), 787–817.
12. Keimel, C., Rothbucher, M., Shen, H., & Diepold, K. J. (2011). Video is a cube. *IEEE Signal Processing Magazine, 28*(6), 41–49.
13. Mohamed, S., & Rubino, G. (2002). A study of real-time packet video quality using random neural networks. *IEEE Transactions on Circuits and Systems for Video Technology, 12*(12), 1071–1083.
14. Ghareeb, M., & Viho, C. (2010). Hybrid QoE assessment is well-suited for multiple description coding video streaming in overlay networks. 8th Annual Communication Networks and Services Research Conference, 327–333.
15. Cancela, H., Amoza, F. R., Rodríguez-Bocca, P., Rubino, G., & Sabiguero, A. (2008). A robust P2P streaming architecture and its application to a high quality live-video service. *Electronic Notes in Discrete Mathematics, 30*, 219–224.
16. Da Silva, A. P. C., Varela, M., de Souza e Silva, E., Leão, R. M. M., & Rubino, G. (2008). Quality assessment of interactive voice applications. *Computer Networks, 52*(6), 1179–1192.
17. Rubino, G., Varela, M., & Bonnin, J.-M. (2006). Controlling multimedia QoS in the future home network using the PSQA metric. *The Computer Journal, 49*(2), 137.
18. Piamrat, K., Viho, C. G., Bonnin, J.-M. M., & Ksentini, A. (2009). Quality of experience measurements for video streaming over wireless networks. IEEE Sixth International Conference on New Generations in Information Technology, 1184–1189.
19. Piamrat, K., Ksentini, A., Viho, C. G., & Bonnin, J.-M. M. (2008). QoE-based network selection for multimedia users in IEEE 802.11 wireless networks. 33rd IEEE Conference on Local Computer Networks (LCN 2008), 388–394.
20. Kim, Y., Pack, S., Kang, C. G., & Park, S. (2011). An enhanced information server for seamless vertical handover in IEEE 802.21 MIH networks. *Computer Networks, 55*(1), 147–158.
21. Lim, W.-S., Kim, D.-W., Suh, Y.-J., & Won, J.-J. (2009). Implementation and performance study of IEEE 802.21 in integrated IEEE 802.11/802.16e networks. *Computer Communications, 32*(1), 134–143.
22. Zhou, L., Chao, H.-C., & Vasilakos, A. V. (2011). Joint forensics-scheduling strategy for delay-sensitive multimedia applications over heterogeneous networks. *IEEE Journal on Selected Areas in Communications, 29*(7), 1358–1367.
23. Lin, C.-P., Chen, H.-L., & Leu, J.-S. (2012). A predictive handover scheme to improve service quality in the IEEE 802.21 network. *Computers & Electrical Engineering, 38*(3), 681–693.
24. Brooks, P., & Hestnes, B. (2010). User measures of quality of experience: why being objective and quantitative is important. *IEEE Network, 24*(2), 8–13.
25. Rumelhart, D. E., Hinton, G. E., & Williams, R. J. (1986). Learning representations by back-propagating errors. *Nature, 323*, 533–536.

26. Recommendation ITU-R BT.500-11. Methodology for the subjective assessment of the quality of television pictures. (2012). http://www.dii.unisi.it/~menegaz/DoctoralSchool2004/papers/ITU-R_BT.500-11.pdf. Accessed March 11, 2013.
27. VTL. (2012). Video trace library. trace.eas.asu.edu. Accessed March 11, 2013.
28. Zhenxing, C., & Satoshi, G. (2011). Efficient motion vector prediction algorithm using pattern matching. *Journal of Visual Communication and Image Representation, 22*(8), 727–733.
29. Majdi, E., Abdelkrim, E., Samy, E., Jean-Luc, D., & Rached, T. (2012). A low-pow oriented architecture for H.264 variable block size motion estimation based on a resource sharing scheme. The VLSI Journal, Available online 3 October 2012, ISSN 0167-9260, doi:10.1016/j.vlsi.2012.09.001.
30. Roma, N., & Sousa, L. (2001). A tutorial overview on the properties of the discrete cosine transform for encoded image and video processing. *Signal Processing Journal, 91*(11), 2443–2464.
31. Quadros, C., Melo, A., Douglas, A., Abelém, A., Cerqueira, E., Neto, A., Riker, A., & Curado, M. (2012). QoE-based packet drop control for 3D-video streaming over wireless networks. 7th IFIP/ACM Latin American Networking Conference, 59201366.
32. Zheng, Y., & Meng, Y. (2011). Modular neural networks for multi-class object recognition. IEEE International Conference on Robotics and Automation, 2927–2932.
33. Choi, H., & Lee, C. H. (2011). Motion adaptive deinterlacing with modular neural networks. *IEEE Transactions on Circuits and Systems for Video Technology, 21*(6), 844–849.
34. So-In, C., Jain, R., & Tamimi, A.-K. (2009). Scheduling in IEEE 802.16e mobile WiMAX networks: key issues and a survey. *IEEE Journal on Selected Areas in Communications, 27*(2), 156–171.
35. Lee, J.-F. F., Liao, W., Chen, J.-M., & Lee, H.-H. (2009). A practical QoS solution to voice over IP in IEEE 802.11 WLANs. *IEEE Communications Magazine, 47*(4), 111–117.
36. Rouil, R., Golmie, N., & Montavont, N. (2010). Media independent handover transport using cross-layer optimized stream control transmission protocol. *Computer Communications, 33*(9), 1075–1085.

Author Biographies

Denis Rosário is Ph.D. student at Federal University of Para/Faculty of Electrical Engineering. His research involves Multimedia, Quality of Experience, and Heterogeneous Wireless Networks. He received Master's Degree in Automation and Systems Engineering by the Federal University of Santa Catarina, Brazil. Since 2010, he has been doing a Ph.D. in Electrical Engineering at the Federal University of Para, Brazil, and currently, he is an exchange student at the Institute of Computer Science and Applied Mathematics, University of Bern, Switzerland. His current research interests include the following: Internet of Things, Mobility, Quality of Experience, and Routing Protocols.

Eduardo Cerqueira (cerqueira@ufpa.br) received his Ph.D. in Informatics Engineering from the University of Coimbra, Portugal, in 2008. He is an associate professor at the Faculty of Computer Engineering of the UFPA in Brazil. His publications include four books, four patents and over than 100 papers in national/international refereed journals/conferences. He is involved in the organization of several international conferences and workshops, including Future Multimedia Networking, Latin America Conference on Communications and Latin American Conference on Networking. He has been serving as a Guest Editor for many special issues of various peer-reviewed scholarly journals. His research involves Multimedia, Future Network, Quality of Experience, Mobility.

Augusto Neto (augusto@deti.ufc.br) is currently Associate Professor at Federal University of Rio Grande do Norte, Brazil. He finished his Ph.D. at the Department of Informatics Engineering, University of Coimbra, Portugal (2008). He authored and co-authored several publications in national and in international journals and conferences. Moreover, he is TPC member and regular reviewer in several networking conferences, and participated in many Portuguese and European research projects. His research interests include: Wireless Networks, Future Internet, Smart Grid, Ubiquitous Computing, Dependable Networking Environmental Intelligence.

André Riker (ariker@dei.uc.pt) is Ph.D. student at University of Coimbra/Department of Informatics Engineering. His research involves Multimedia, Artificial Intelligence, Mobility Models and QoE.

Roger Immich (immich@gmail.com) is Ph.D. student at University of Coimbra/Department of Informatics Engineering. His research involves Wireless Networks, QoE.

Marilia Curado (marilia@dei.uc.pt) is an Assistant Professor at the Department of Informatics Engineering of the University of Coimbra, Portugal, from where she got a Ph.D. in 2005. Her research interests are multimedia, QoE, Mobility, Routing, and Resilience. Se has over than 100 papers in national/international refereed journals/conferences. She has participated in several national projects, in Networks of Excellence from IST FP5 and FP6, in the IST FP6 Integrated Projects, EuQoS and WEIRD, and on ICT FP7 STREPs MICIE and GINSENG.